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Relationship between environmental variables and surface activity of scorpions in the Arid Chaco ecoregion of Argentina

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Abstract. Many environmental factors may influence the activity of scorpions in arid ecosystems. In this study, we examined the effects of such factors on scorpion activity at a mature and a secondary forest site in the Chancaní Reserve (Arid Chaco ecoregion in Córdoba, Argentina). Scorpions were collected using pitfall traps, and their nocturnal activity was observed by means of UV light during 14 nights. Temperature, air humidity, atmospheric pressure, and wind velocity were measured, and the percentage of visible moon was estimated. A total of 440 scorpions, representing seven species belonging to two families (Bothriuridae and Buthidae), were observed in the study area. *Brachistosternus ferrugineus* was the species most commonly observed using both methods. Mature and secondary forest shared slightly more than 50% of species. Surface activity of scorpions observed with the two methods differed significantly between the two areas. Surface activity of all scorpions and of *B. ferrugineus* were negatively related to the phase of the moon and positively related to air temperature. Physical factors thus have important effects on scorpion activity.

Additional key words: Scorpiones, Chancaní, diversity, habitat, moonlight

Scorpions are solitary predators that are found in all continents except Antarctica. They feed on terrestrial arthropods (e.g., insects, spiders, and even other scorpions), and they are in turn preyed on, especially by vertebrates. Although scorpions are most diverse in deserts, they also occur in all other terrestrial habitats except for tundra, high-latitude taiga, and some high-elevation mountaintops (Polis 1990).

Daily and seasonal patterns of scorpion activity are affected by both biological factors (e.g., the presence of predators, prey, or potential mates) and environmental factors (Polis 1990; Hoshino et al. 2006). Soil type, topography, hydrology, soil humidity, food resources, and especially temperature and precipitation (Polis 1990; Dias et al. 2006; Yamaguti & Pinto-da-Rocha 2006) have been shown to affect scorpion activity in arid region ecosystems. Temperature profoundly affects many processes, including growth (Angilletta et al. 2004), locomotor performance (Forsman 1999), and surface activity (Bradley 1988). Scorpions generally maintain their

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preferred body temperatures through behavioral thermoregulation (Carlson & Rowe 2009). Most species of scorpions are more active during both warm (Polis 1980; Polis & McCormick 1986) and humid (Skutelsky 1996) weather conditions, a trait that may help them maximize body temperature, while minimizing water loss (Carlson & Rowe 2009).

The lunar cycle is also likely to have marked effects on members of nocturnal desert communities, because moonlight is very apparent in open habitats and is a powerful source of illumination that cannot be neglected from the perspective of visual communication in nocturnal species (Penteriani & Delgado 2009). The luminance of a full moon (~0.25 lux) is ~25 times greater than that of a quarter moon, and 250 times greater than that of a moonless, clear, starry night sky (Foster & Roenneberg 2008). Several studies have shown that moonlight influences the behavior of both vertebrates and invertebrates (Tigar & Osborne 1999; Cryan & Brown 2007), and others have also noted that scorpions are much less active on moonlit nights (Hadley & Williams 1968; Tigar & Osborne 1999), and tend to ambush prey under bushes in such conditions, rather than foraging in the

open (Skutelsky 1996). Polis (1980) did not observe an overall reduction in scorpion surface activity during periods of full moon, but both mating and feeding occurred significantly less frequently in these periods.

Despite their widespread distribution and their ecological importance, scorpion ecology has received little attention. Only a few detailed ecological studies have been published to date, almost all in western North America or Australia (e.g., Koch 1978; Polis 1980; Polis & McCormick 1986; Jiménez-Jiménez & Palacios-Cardiel 2010). These studies mostly concern members of only a few species in only three genera: Smeringurus mesaensis (Stahnke 1957) and Paruroctonus utahensis (WILLIAMS 1968) (both Vaeiovidae) in North America, and a few members of the genus Urodacus (Urodacidae) in Australia. A few studies concerning scorpion ecology have been carried out in South America (Agusto et al. 2006; Yamaguti & Pinto-da-Rocha 2006; Araújo et al. 2010), but these used only pitfall traps as a method of capture.

This study is the first intensive project on the ecology of scorpions in the Arid Chaco ecoregion, using both pitfall traps and UV light as sampling methods. The Chancaní Reserve was chosen as a study site, as it includes the highest number of sympatric scorpions documented in Argentina (nine species represented by two families: Bothriuridae and Buthidae) (Acosta 1995). Most scorpions there are members of grounddwelling species. Members of eight of these species are active during the summer, and one is active in the winter. Bothriurids in general live in burrows that they dig, while many genera of buthids live under logs, rocks, or tree bark (Polis 1980). Scorpion activity is mainly nocturnal (Polis 1990). Most scorpions are first seen at dusk as they leave their burrows for the surface, and a peak in activity commonly occurs soon after dusk. This is followed by a gradual decrease in the number seen until dawn (Hadley & Williams 1968; Toren 1973; Polis 1980, 1990).

The main goal of this research was to evaluate the influence of moonlight (as indicated by the phase of the moon) and other factors, such as air temperature, relative humidity, atmospheric pressure, and wind speed, on the surface activity of scorpions (measured as the number of individuals on the ground surface). The diversity of scorpions was also compared in two different areas, mature and secondary forest.

Methods

Study sites

The study was conducted in 2009 in the 4960 ha Parque Provincial y Reserva Forestal Chancaní (Chancaní Reserve, 31°22′13.21″S, 65°27′13.75″W). The Chancaní Reserve is located in the southernmost portion of the Arid Chaco ecoregion (NT0701 in Olson et al. 2001) in Córdoba province, Argentina (Fig. 1A). The Chancaní Reserve was created and fenced in 1986, and its vegetation has remained free from human disturbance since then (Cabido & Pacha 2002). Vegetation in the reserve is dry xerophyllous woodland. The canopy is discontinuous and ~15 m high, dominated by the trees Aspidosperma quebracho-blanco Schltdl 1861 and Prosopis flexuosa D.C. 1825. The shrub stratum (~4 m high) is thorny, dense, and almost continuous, dominated by Larrea divaricata CAV. 1800, Mymozyganthus carinatus (GRISEB.) BURKART 1939, and Acacia furcatispina Burkart 1947 (Carranza et al. 1992). The reserve supports forest stands that are close to climax conditions. The climate is highly seasonal, with a pronounced dry season. Annual rainfall averages 450 mm, concentrated during the summer (October-March). In the dry winter season (April–September), the water balance is negative, resulting in a soil humidity deficit. Mean annual temperature is 18°C, with a mean value of 25°C in the warmest month (January, with maximum temperatures reaching 45°C during the day) and 10°C in the coldest month

In the Arid Chaco ecoregion, the fire season usually coincides with the frost season, from May to September (Kunst & Bravo 2003). Wildfire affected the Chancaní Reserve in December 1994. It was an out of season, high-intensity fire that started under extremely dry conditions due to a long delay in the onset of the rainy season. The fire covered ~32,000 ha of Arid Chaco forest, affecting 230 ha within the western boundaries of the Chancaní Reserve. This fire generated a secondary forest area next to the main forest area (Fig. 1A).

Because of the increasing degradation of Arid Chaco forest and the lack of well-preserved mature forest in the entire region, the unburned area (mature forest) and burned area (secondary forest) were unique in terms of management history; hence, we were unable to sample truly replicated plots (sensu Hurlbert 1984) or extrapolate results beyond the areas surveyed. Despite the lack of replicates, our design had some singularities that allowed us to evaluate the indirect effects of the 1994 fire within the areas sampled: (a) burned and unburned areas had a known management history, (b) vegetation in both areas was similar before the fire, and (c) burned and unburned areas are geographically close, which reduces biases in results due to local climate variability (Pelegrin & Bucher 2010).

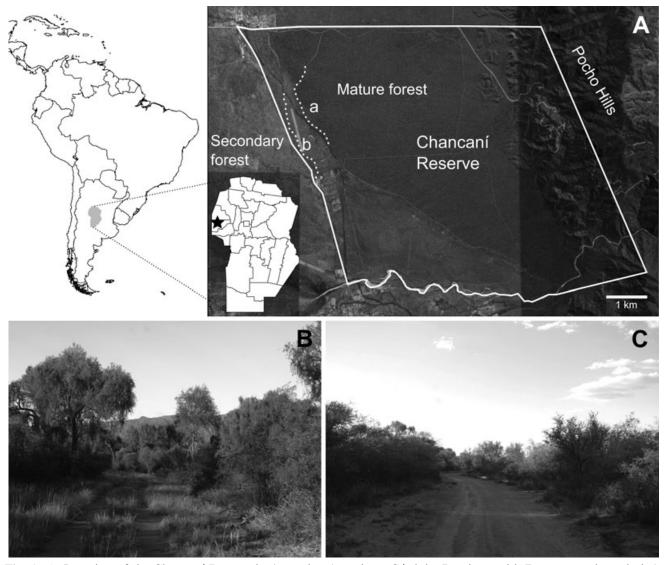


Fig. 1. A. Location of the Chancaní Reserve in Argentina (star, inset Córdoba Province, with Department boundaries) and sampling areas (transects sampled indicated by dashed lines: a, mature forest; b, secondary forest). **B.** Mature forest. **C.** Secondary forest. More vegetation and vertical strata can be observed in mature forest than in secondary forest.

Experimental design

Two sites were selected within Chancaní Reserve (Fig. 1A), one representative of mature forest (Fig. 1B), and one of secondary forest (Fig. 1C). At each site, 15 transects (50×6 m) were established. Transects were separated from each other by 70 m inter-transects. Transects passed along and on the main roads in each sector, due to the difficulty of accessing and observing scorpions inside the dense forest. The two sites were on roads located as close together as possible (230–760 m to avoid the potential effect of changes in the soil on the scorpion communities. Scorpion diversity and abundance in

the Chancaní Reserve shift toward the eastern hills, going from typical Arid Chaco species to species most commonly found in rocky environments (Acosta 1995). Except for males in the reproductive season, which can walk up to 40 m, scorpions have a limited home range (the majority of surface activity occurs within 1 m of the burrow for individuals of all ages: Polis et al. 1985), so we assume that scorpion interchange between sites is low.

Sampling lasted about 2 h after dusk (it began at 9 pm and ended around 11 pm), as these were the main activity hours of scorpions at the study site (M.F. Nime, unpubl. data). The main sampling took place in November 2009 for 16 nights (from new

moon to full moon), alternating the sampling site (eight nights at each site). On one night of mature forest site sampling (41% of moon visible), no scorpions were observed, presumably as a consequence of rainy weather; data from this sampling date were not included in further analyses. The same thing happened on one night of secondary forest sampling (50% of moon visible), and data from this sampling date were also not included. During one full moon night of mature forest sampling, the sky was cloudy; data from this date were not included in analyses of the effect of moon phase on surface activity. Cloud cover was minimal on the remaining nights. Sampling consisted of walking slowly along the transect with the aid of a portable ultraviolet (UV) lamp (a Maglite® flashlight modified with UV LED attachments). Irradiation with UV causes scorpions to fluoresce, which allows all stages of scorpion to be easily detected in the dark (Honetschlager 1965). When located, scorpions were captured, classified by species and sex (male, female, and juvenile), and then were released in the same place.

Pitfall traps were used as another sampling method; these data were used only for comparing surface activity, species richness, Shannon indices (H'), and similarities (Jaccard coefficient) between sites. Along each of the 15 inter-transects, 5 plastic containers (8 cm diameter×11 cm depth) were buried with their openings at ground level. Each contained 300 cm³ of saturated saline. The five pitfall traps along each inter-transect were separated by 10 m; the first and last one were located 10 m away from the ends of the inter-transect. The five traps along each inter-transect were positioned on the left or right sides of the inter-transect in an alternating fashion. A total of 75 traps (5 per inter-transect, 15 inter-transects) were deployed per site. The traps remained at each site for a period of 16 d. They were checked daily, and their contents transferred to ethanol 80%. Scorpions were classified by species and sex.

Environmental measures

For each sampling night, we obtained the percentage (0% [new moon]–100% [full moon]) of visible moon using the program MoonTool (http://www.fourmilab.ch/moontoolw). We assumed that full and new moons represented maximum and minimum moonlight levels, although light levels were not measured. On each transect, at the time of initial observation, the following variables were measured: air temperature (°C at 120 cm above ground level), relative humidity (%), atmospheric pressure (Pa), and

wind velocity (m s⁻¹ at 2 m above ground level and at the soil surface). Air temperature, relative humidity, and wind speed were measured with a 4 in 1 Environment Tester (Lutron LM-8000). Atmospheric pressure was measured with a Digital Compass and Altimeter (Sinometer FOS WS-110).

Statistical analysis

Analyses were conducted using InfoStat Professional v. 2011 p (Di Rienzo et al. 2011). First, we related environmental variables to surface activity of all scorpions (the abundance of all species was pooled). Second, we related environmental variables to surface activity of the most common species. Finally, we related environmental variables to surface activity of each sex of the most common species. For the analysis of this dataset, we used a Generalized Linear Mixed Model (GLMM) with environmental variables (percentage of moon visible, temperature, relative humidity, atmospheric pressure, and wind velocity) and site as fixed factors, and transect as a random factor. A Poisson error distribution with a log-link function was used. Significance was set at p<0.05. For the GLMM analysis, only data taken by the UV light method were used.

For each site and for each observation method (UV light and pitfall traps), surface activity was estimated as the number of scorpions captured. Species richness was calculated as the number of scorpion species at each site. Diversity of scorpions was calculated using the Shannon Index (H') (Krebs 1978; Moreno 2001). Similarities between communities were calculated by the Jaccard coefficient: Cs=c/(s1+s2-c), where s1 and s2 are the number of species found in communities 1 and 2, respectively, and c is the number of species found in both communities (Moreno 2001). To calculate surface activity, species richness, the Shannon Index, and the Jaccard coefficient, we included data taken by both methods. Differences in surface activity between sites were analyzed with GLMM. Differences in richness of species and Shannon Index between sites were analyzed using t-tests.

Results

Surface activity

A total of 440 scorpions representing seven species belonging to two families (Bothriuridae and Buthidae) were observed with both methods in the study area. Members of the following species were found: *Brachistosternus ferrugineus* (THORELL 1877),

Scorpion species	UV light				Pitfall traps				Total	
	Mature forest		Secondary forest		Mature forest		Secondary forest			
	\overline{N}	0/0	N	%	\overline{N}	%	N	%	N	%
Brachistosternus ferrugineus	196	88.3	118	81.4	23	52.3	21	72.4	358	81.4
Brachistosternus pentheri	0	0	20	13.8	0	0	1	3.4	21	4.8
Timogenes elegans	8	3.5	1	0.7	13	29.5	5	17.2	27	6.1
Timogenes dorbignyi	5	2.2	0	0	6	13.6	0	0	11	2.5
Bothriurus cordubensis	0	0	1	0.7	2	4.5	1	3.4	4	0.9
Zabius birabeni	12	5.3	5	3.4	0	0	1	3.4	18	4.1
Tityus confluens	1	0.4	0	0	0	0	0	0	1	0.2
Total	222	100	145	100	44	100	29	100	440	100

Table 1. Scorpion species sampled at mature forest and secondary forest in Chancaní Reserve, using UV light and pit-fall traps methods. Numbers are given as specimens sampled (N) and percentage of the total (%).

Brachistosternus pentheri Mello-Leitão 1931, Timogenes elegans (Mello-Leitão 1931), Timogenes dorbignyi (Guérin-Méneville 1843) and Bothriurus cordubensis Acosta 1995 (Bothriuridae), and Zabius birabeni Mello-Leitão 1938 and Tityus confluens Borelli 1899 (Buthidae).

Table 1 shows the number of specimens of each species collected from both sites using UV light and pitfall traps. UV light sampling yielded far more scorpions than the pitfall method: 367 scorpions were collected by the first method, and only 73 by the second. Members of all seven species were observed during sampling with UV light, but only six species appeared in pitfall traps. *Brachistosternus ferrugineus* was by far the most common species sampled with both methods and at both sites, accounting for 85.6% of the total number of scorpi-

ons sampled from both sites with UV light, and 60.3% of the total number of scorpions sampled from both sites using pitfall traps. *Tityus confluens* was the least common species, with only one individual observed, using the UV light method; that individual represented 0.27% of the total number of scorpions collected using UV light.

The Jaccard index was Cs=0.57, indicating that mature and secondary forest share slightly more than 50% of species. Members of four of the seven species recorded with both methods of capture were found at both sites: *B. ferrugineus, T. elegans, B. cordubensis,* and *Z. birabeni,* while members of three species were present at one site and not the other: *T. dorbigny* (n=11) and *T. confluens* (n=1) were present only in mature forest, and *B. pentheri* (n=21) was present only in secondary forest (Fig. 2).

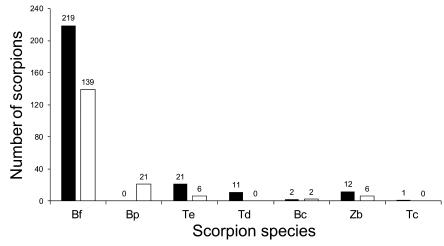


Fig. 2. Species and number of scorpions found in mature (filled bars) and secondary forest (open bars) during the sampling with both methods (UV and pitfall traps). Bf, *Brachistosternus ferrugineus*; Bp, *Brachistosternus pentheri*; Te, *Timogenes elegans*; Td, *Timogenes dorbignyi*; Bc, *Bothriurus cordubensis*; Zb, *Zabius birabeni*; Tc, *Tityus confluens*.

Surface activity of the scorpions observed with both methods differed significantly between the two areas (N=30, c^2 =19.38, p<0.0001). Mature forest had significantly higher surface activity (17.03 \pm 1.62 [S.E.] scorpions per transect) than did secondary forest (11.14 \pm 1.17 scorpions per transect). Species richness was not significantly different (N=30, t=1.34, p=0.1899) between mature forest (2.60 \pm 0.91 species per transect) and secondary forest (2.13 \pm 0.99 species per transect). Species diversity was not significantly different (N=30, t=0.95, p=0.3490) between mature forest (H'=0.69) and secondary forest (H'=0.72).

The sex ratio of the most abundant species, *B. ferrugineus*, sampled with UV light was 1:1.3 males: females in mature forest, and 1:1.7 in secondary forest. In pitfall traps, the sex ratio of *B. ferrugineus* was 1:2.6 in mature forest, and 1:2.33 in secondary forest.

Influence of environmental variables

In the final analysis we considered only soil wind speed, because air and soil wind speed were strongly correlated. Minimum, maximum, and mean values of the various environmental parameters at each site are shown in Table 2.

Results of the analysis for all scorpions (n=367) and for B. ferrugineus (n=314) sampled with UV light were similar, so we will refer in the text only to the result for all scorpions, unless clarification is considered necessary. Table 3 shows the values for all scorpions and for B. ferrugineus. Surface activity of all scorpions was negatively related with percentage of visible moon ($c^2=57.46$, p<0.0001). In the analysis of both sites separately, the relationship between surface activity of all scorpions and the percentage of visible moon was also negatively correlated (mature forest, r=0.9 (Fig. 3A); secondary forest, r=0.87 (Fig. 3B); p<0.0001). In addition, surface activity of all scorpions was positively related to air temperature ($c^2=18.44$, p<0.0001) (Table 3). Site was a significant factor ($c^2=15.51$, p<0.0001). No significant relationship was detected between surface activity and relative humidity, atmospheric pressure or soil wind speed (Table 3).

Percentage of visible moon was the only variable that showed a significant negative relationship with surface activity for males (n=97), females (n=140), and juveniles (n=77) of *B. ferrugineus* (c^2 =26.84, p<0.0001 males; c^2 =24.83, p<0.0001 females; c^2 =6.74, p=0.0094 juveniles). Site was significant as a factor only for males (c^2 =11.52, p=0.0007) and juveniles (c^2 =5.26, p=0.0218).

Table 2. Minimum (Min), maximum (Max), and mean values for the measured environmental factors at each mature and secondary forest site.

Variables		Mature forest	İ	Secondary forest			
	Min	Max	Mean	Min	Max	Mean	
Air temperature (°C)	24.2	34.4	29.5	25.3	33	29.5	
Relative humidity (%)	20.2	59.6	40.9	14.2	59.2	41.7	
Atmospheric pressure (Pascals)	100700	101800	101230	100500	101800	101080	
Air wind velocity (m s ⁻¹)	0	3.89	0.78	0	12.86	1.75	
Soil surface wind velocity (m s ⁻¹)	0	4.06	0.33	0	7.28	0.83	

Table 3. Generalized linear regression for the relation between surface activity of all scorpions and of *Brachistosternus* ferrugineus and environmental variables, including site effect (variables taken on 14 nights). Significant differences (p<0.05) are in bold.

Environmental variables	A	ll scorpions	S	Brachistosternus ferrugineus			
	Chi-square	df	p-value	Chi-square	df	p-value	
Percentage of moon	57.46	1	< 0.0001	55.95	1	< 0.0001	
Air temperature	18.44	1	< 0.0001	14.24	1	0.0002	
Relative humidity	0.81	1	0.3668	0.29	1	0.5930	
Atmospheric pressure	2.99	1	0.0838	2.79	1	0.0951	
Soil wind speed	0.31	1	0.5766	3.39	1	0.0656	
Site	20.42	1	< 0.0001	23.43	1	< 0.0001	

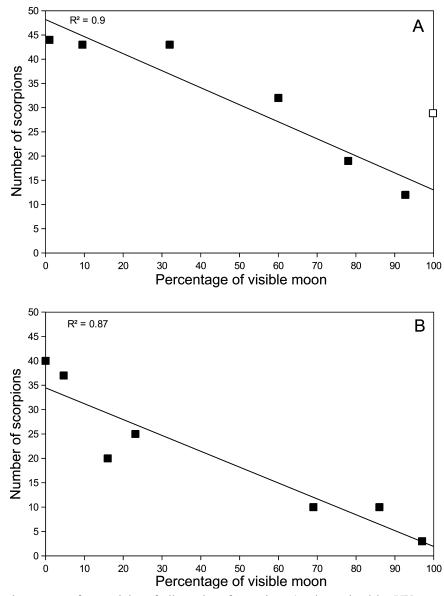


Fig. 3. Relationship between surface activity of all species of scorpions (as determined by UV sampling) and the phase of the moon. A. Mature forest. Open square (\square) represents one night in mature forest with 100% moon, but cloudy sky; this value was not included in the regression analysis. B. Secondary forest. R^2 =coefficient of determination of linear regression.

Discussion

Surface activity

Surface activity was higher in mature forest than in secondary forest. This higher abundance could be due to characteristics of the habitat in mature forest that favor a high density. For example, the presence of a higher stratum compared with secondary forest (M.F. Nime, unpubl. data) could be influencing scorpion abundance by providing a better foraging

area where moonlight cannot penetrate completely, or supporting more abundant prey. Some species of scorpions reach their highest densities only in areas with extensive ground cover from rocks, logs, or other vegetation litter (Koch 1978; Cala-Riquelme & Colombo 2011). However, an exhaustive analysis of the characteristics of the habitats studied here remains to be carried out.

In contrast to surface activity, species richness and diversity were not significantly different between the two sites. Mature forest included members of only one more species (six species) than did secondary forest (five species). The Shannon index was low and similar at both sites, due to the domiof Brachistosternus ferrugineus, accounted for >82% of the individuals in the mature forest, and for >79% of the individuals in the secondary forest. The dominance of this species causes the reduction in diversity. However, specimens of B. pentheri were found only in secondary forest. This psammophilic species is common in Monte habitats (drier shrub plains of western Argentina), and is only occasionally found in Arid Chaco environments (Acosta 1995; Ojanguren-Affilastro 2005). It appears that the modification of the forest and soil produced by fire offered an opportunity for B. pentheri to increase its abundance in the secondary forest in the arid Chaco. In contrast, both species of Timogenes were more common in the mature forest than in the secondary forest. As members of both species are considerably larger than members of B. ferrugineus, perhaps the reduced cover in the secondary forest has stronger effects on them, as they are more conspicuous to predators. Tityus confluens was the least common species (n=1; 0.23% of the total number of collected scorpions); this species is typically found in low abundance in the Arid Chaco (Acosta 1995).

The observed sex ratio in B. ferrugineus was in favor of females in both sites with both methods, and shows that females of B. ferrugineus are more prevalent during November. However, scorpion sex ratio could change during the mating season, showing peaks of male activity in the middle of the season, and more females active in the early and late season, as observed in Smeringerus mesaensis (Polis 1980). Our study was conducted at the beginning of the mating season of B. ferrugineus (November), when more females are active. We expect the true sex ratio to be around 1:1, but with differential mortality favoring females, and males generally not surviving to the next mating season (M.F. Nime & C.I. Mattoni, unpubl. data), as already observed in S. mesaensis (Polis & Farley 1980). Other reports of female-biased sex ratios in scorpions (e.g., Warburg 1997; Zarei et al. 2009) may also be affected by the season when the surveys were conducted.

We noticed several important differences between the sampling methods. The UV light method was much more effective in terms of estimating scorpion abundance. In addition, the frequencies of different species sampled were quite different between methods. This is likely due to biases inherent in pitfall trap sampling: wanderer species are more easily caught in pitfall traps than species whose members are sit-and-wait predators. Only one individual of one species of buthid scorpion (a family whose members are mostly sit-and-wait predators) was collected in pitfall traps; however, with the UV light method, 18 specimens of two buthid species were detected (Table 1). This study shows the importance of using both methods as complementary in scorpion ecology.

Surface activity and environmental variables

More scorpions were observed during new moon than full moon, confirming that there is a negative relationship between moon phase (that is, intensity of moonlight) and scorpion surface activity. Other researchers have also noted that scorpions are much less active on moonlit nights (Hadley & Williams 1968; Tigar & Osborne 1999). For example, adults of *Buthus occitanus israelis* (Shulov & Amitai 1959) showed reduced activity on simulated moonlit nights compared with dark nights, and those that were active ambushed prey under bushes rather than out in the open (Skutelsky 1996).

Scorpions detect prey by sensing air and surface vibrations, rather than by vision (Brownell 1984; Polis 1990), and so illumination is not likely to have a direct effect on their foraging behavior. Rather, moonlight may affect scorpion behavior indirectly, through changes in risk of predation or changes in prey availability. Scorpions are intermediate-level predators that must both capture prey and avoid predation (Polis 1991). An increased risk of vertebrate predation on intermediate predators has been implicated in reducing their foraging activity during full moon compared with new moon (Skutelsky 1996). Members of several scorpion species are preved upon by visually orienting nocturnal birds, such as owls (Polis et al. 1981; Skutelsky 1996). An alternative explanation for the scorpions' reaction to moonlight is that their behavior indirectly reflects the behavior of their prey. If their insect prey are less active or stay closer to bushes on moonlit nights, it could be beneficial for scorpions to do the same (Skutelsky 1996).

That temperature influences scorpion activity has been observed many times previously (Toren 1973; Polis 1980; Bradley 1988; Benton 1992). The results obtained in the present study indicate that higher temperatures favor scorpion surface activity. Polis (1980) showed that members of *S. mesaensis* responded to variation in temperature, even within seasons. Nocturnal air temperature was positively correlated with activity levels in adults of *Paruroctonus*

utahensis, and it was observed that members of this species retreat into their burrows when the temperature falls below 6–8°C (Bradley 1988).

The influence of temperature on locomotor performance is ecologically important for many organisms, as it impacts both hunting ability and predator avoidance through such activities as sprinting (Bauwens et al. 1995), flying (Machin et al. 1962), and swimming (Turner et al. 1985). For this reason, preferred body temperature is often strongly correlated with the optimal temperature for sprinting capacity (Bauwens et al. 1995; Forsman 1999), providing evidence that ectothermic organisms typically select body temperatures that maximize their locomotor capabilities. If a prey organism's ability to survive encounters with and escape from predators is dependent on locomotor performance, then maintaining preferred body temperatures will enhance survival in the face of predation; indeed, this has been demonstrated in wild populations (Christian & Tracy 1981). As scorpions are ectotherms, we may expect a relationship between muscular activity and temperature (Benton 1992). Perhaps a higher metabolic rate at higher temperatures and faster running speed means they have a higher probability of escaping predation (Carlson & Rowe 2009). The effect of temperature on metabolic rate has been documented for at least 11 species of scorpions (Terblanche et al. 2007). Temperature appears to affect surface activity in male, female, and juvenile scorpions in a similar way, as noted by Yamashita (2004).

Although the effect of clouds was not considered in the statistical analysis, the observation of high surface activity (n=29) on one cloudy night, despite the presence of a full moon suggests that there may be an effect of cloud cover on scorpion activity. On that night, presumably cloud cover significantly reduced moonlight penetration through the atmosphere. An effect of cloud cover has been previously demonstrated in other animal groups, for example, on migration of bats (Cryan & Brown 2007), the activity of rodents (Vickery & Bider 1981), and light trap captures of lepidopterans (Yela & Holyoak 1997).

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